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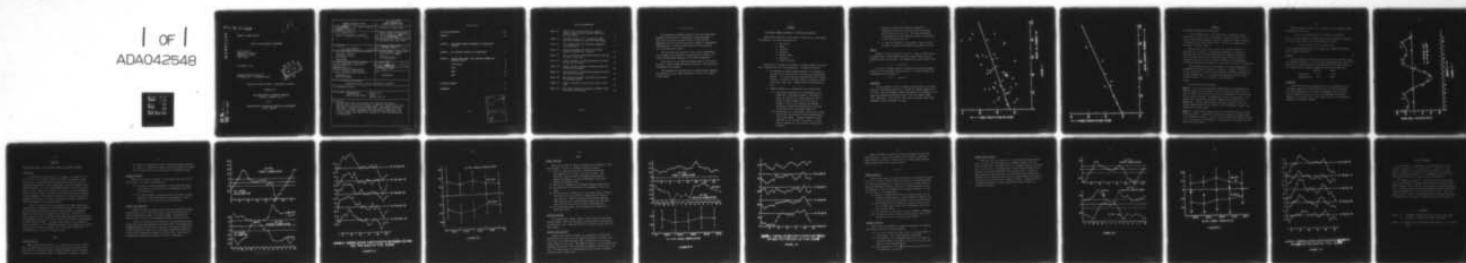
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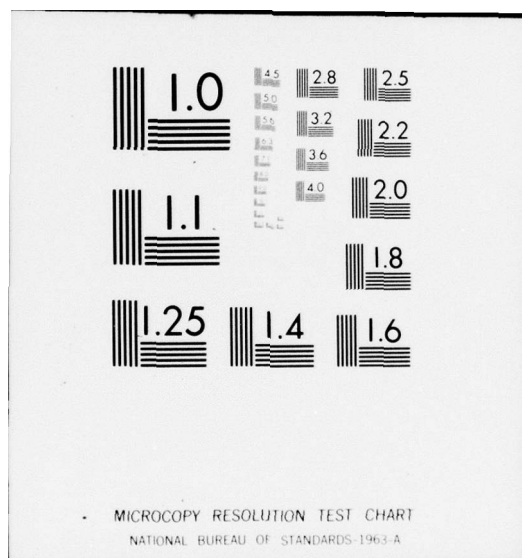
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STUDY OF THE EQUATORIAL IONOSPHERE

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A B S T R A C T

The amplitude and Faraday rotation of the 136.47 MHz signal radiated by ATS-3 has been determined on a continuous basis from 1-9-71 to 28-10-76 at Legon (5.63°N , 0.19°W , dip 8°S). During this time the satellite was kept on station at approximately 70°W longitude, so that its elevation was 12° and its azimuth -92° for an observer at Legon.

The above data are used here to give a better determination of the sunspot cycle dependence of scintillation, as well as the annual and semi-annual component of the seasonal dependence.

Final results on the inter-correlation among SI, TEC, and KP are given. Daily, monthly and annual variations in the correlation coefficients are presented.

The dependence of scintillation on elevation angle, longitude and frequency are still under investigation, and are not included in this report.

CHAPTER 1

THE SUNSPOT NUMBER DEPENDENCE OF SCINTILLATION ACTIVITY

Scintillation activity at Legon shows a dependence on a wide variety of parameters. The chief among these are:

- a. Time of day
- b. Season
- c. Elevation
- d. Longitude
- e. Sunspot number
- f. Frequency
- g. Magnetic activity.

We here wish to isolate the dependence on sunspot number R , and will try to eliminate the other six dependencies. We proceed as follows:

1. To eliminate the marked diurnal variation of scintillation, we shall take the mean value of the night time scintillation indices. The latter have been determined for each 15 minute interval. We take the 40 values which fall between 19 hours and 05 hours local time. Monthly means of these values are used.
2. Seasonal dependence is eliminated in two different ways.
 - (i) The seasonal variation can be approximated by an annual and a semi-annual sinusoid. The phases of these are such that the period January to June is nearly the mirror image of the period July to December. Hence we can eliminate the seasonal dependence by taking semi-annual means of scintillation index (S.I.) and sunspot number (R).
 - (ii) Alternatively, one can produce a scatter plot of the monthly mean scintillation activity against monthly mean sunspot number. Seasonal dependencies will contribute to the scatter of the points. A least squares straight line will yield the sunspot-cycle dependence.

3. Longitude, elevation and frequency dependence is eliminated by using the 136.47 MHz beacon on satellite ATS-3 from 1-9-71 to 31-12-75. The satellite remained at approximately 70° west during the period; the elevation as seen from Legon being 12°.
4. All days were included in the analysis; hence no effort was made to eliminate the dependence on magnetic activity.

RESULTS:

Results are shown in Figures 1-1 and 1-2. Using a scatter plot of 52 monthly means of scintillation index and sunspot number, we fit a straight line by least squares. The equation of the best straight lines is:

$$\text{S.I.} = .34 R + 26$$

If we plot six-month averages of scintillation index and sunspot number, we get the 8 points shown in Figure 2. The best straight line is expressed by the equation:

$$\text{S.I.} = .44 R + 21$$

DISCUSSION:

The two straight lines lie reasonably close together in the range covered by experimental points (i.e. the range of sunspot numbers from 0 to 100). Data from sunspot maximum could improve the usefulness of the curves by providing experimental points in the high sunspot number (100 - 150) range. This cannot be done easily at present, since other dependencies would contaminate the data.

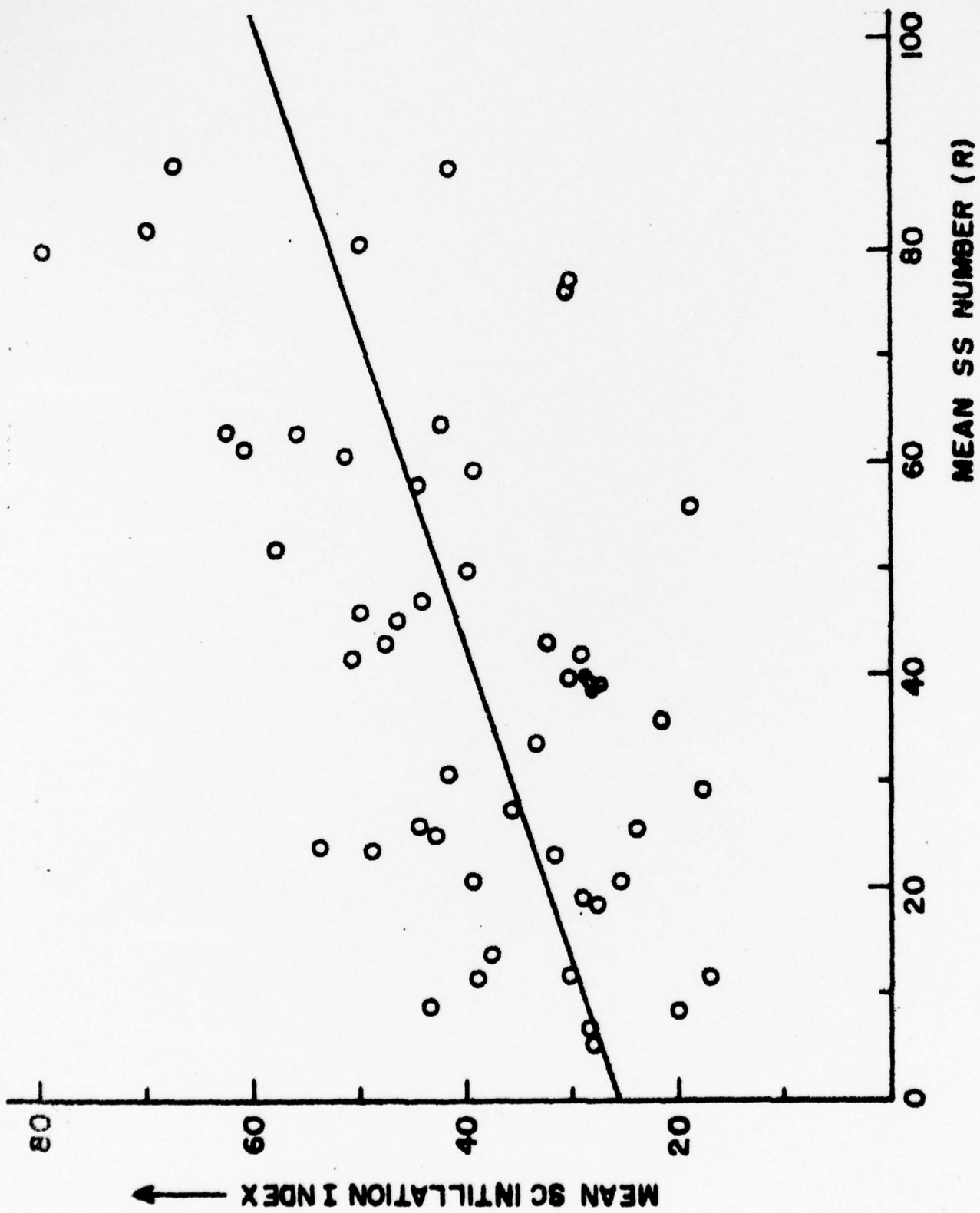


FIGURE 1-1

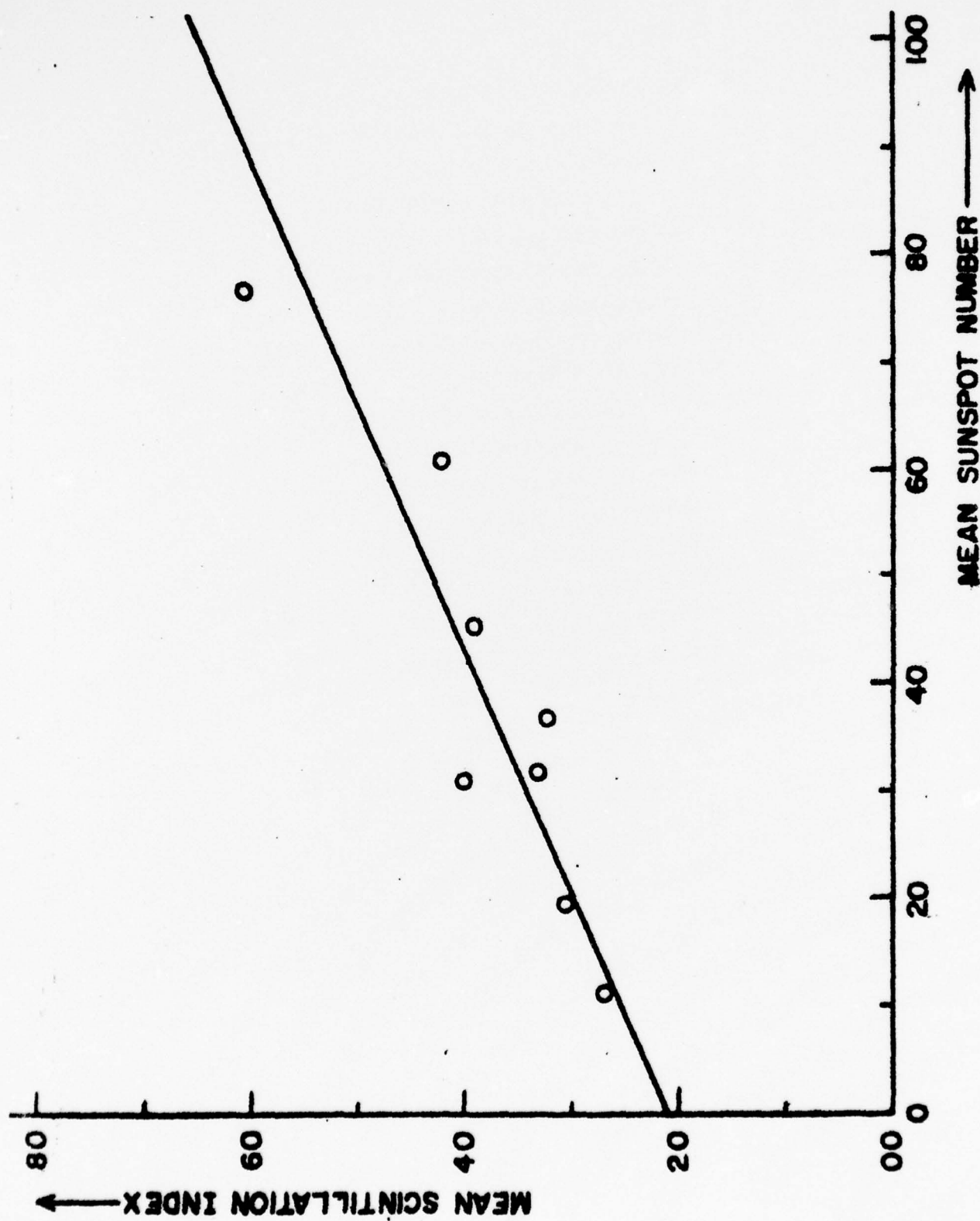


FIGURE 1-2

CHAPTER 2

THE SEASONAL VARIATION OF SCINTILLATION

As was mentioned in the preceding chapter, scintillation shows a dependence on a wide variety of parameters. These include time of day, season sunspot number, magnetic activity, elevation of source, longitude of observer and the radio frequency used. We have just determined the dependence on sunspot number.

The same data can be used to isolate the seasonal variation of scintillation. As above, we eliminate the dependence on longitude of observer, elevation of source and frequency by confining ourselves to the 136.47 MHz beacon on ATS-3 during the period 1-9-71 to 31-12-75. During this time the satellite was kept on station at 70° W longitude. Elevation and azimuth for an observer at Legon were 12° and 268° respectively.

Since magnetic activity can be assumed, to a first approximation, to be randomly distributed, we shall not attempt to eliminate it directly. If the data extend over a sufficiently long period, it should be smoothed out in the averaging process. The sunspot cycle dependence being now known, we shall eliminate it in the process of our calculations.

METHOD:

Two methods suggest themselves.

METHOD A: As in the previous chapter, monthly means of scintillation were obtained over the 52 month period. These 52 values were gathered into 12 groups by month, and a mean for each of the 12 determined. A curve was then fitted to these 12 points. The method has the merit of simplicity. If it extends over a sufficiently long time, sunspot cycle dependence will be smoothed out. But the method tends to give undue weight to values near sunspot maximum (when they are largest), and to discriminate against values obtained near sunspot minimum.

METHOD B: In this method, monthly means of scintillation index and sunspot number are plotted. A straight line is fitted, considering sunspot number as the independent variable. For each of the 52 months, the percent deviation of S.I. from this line is determined. These 52 percent deviations are then treated as outlined above.

The curve that is fitted to the 12 points by a least squares method is initially of the form:

$$Y = B_1 + B_2 \cos(\omega t) + B_3 \sin(\omega t) + B_4 \cos(2\omega t) + B_5 \sin(2\omega t)$$

where ω has the value of 2π radians/year, and t is measured in fractions of a year. This equation is later converted to the form:

$$Y = A_0 + A_1 \cos(\omega t - \phi_1) + A_2 \cos(2\omega t - \phi_2)$$

so that the amplitude and phase of the annual and semiannual components can be examined separately.

RESULTS:

$2 \cdot \pi \pi$

Both the methods mentioned above were used, and the resultant curves were virtually identical. We give only the second method here, since it was assumed to be slightly superior. The resultant curve is shown in Figure 2-1. Values of the constants obtained are shown in the table below:

	Amplitude	Phase
Annual term	28.4	-3.5°
Semiannual term	15.0	169.9°

DISCUSSION:

We note that the annual component has twice the amplitude of the semi-annual component; while the phases are 0° and 180° respectively to a first approximation. This curve is remarkably similar, in both relative amplitude and phase, to the curve describing the seasonal behaviour of Q_0 (Koster, 1976). The possible origin of this remarkable similarity is discussed elsewhere.

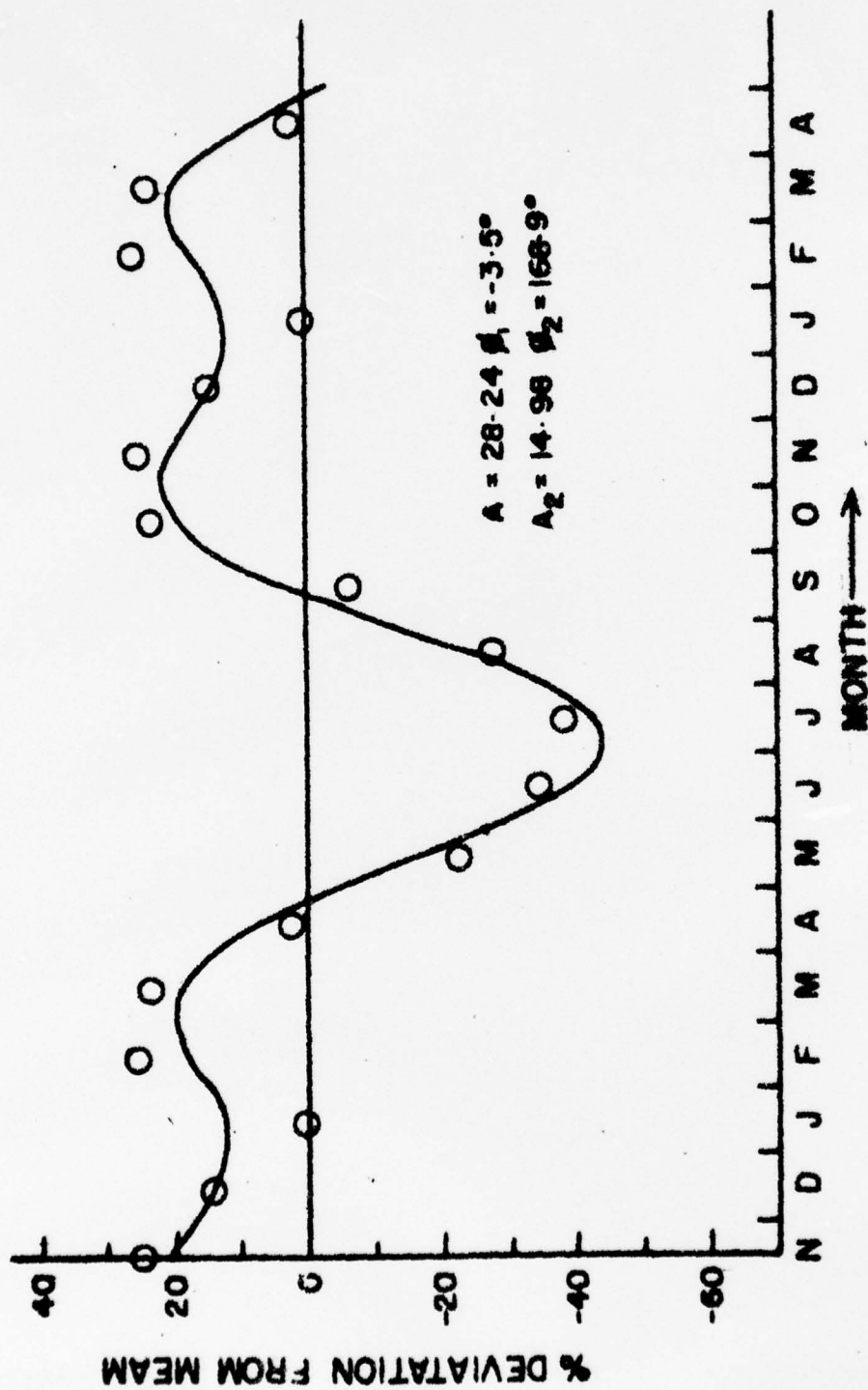


FIGURE 2-1

CHAPTER 3

SCINTILLATION INDEX, TOTAL ELECTRON CONTENT, AND MAGNETIC ACTIVITY

INTRODUCTION:

In Interim Scientific Report No.2, a chapter was devoted to the above topic. In the meantime, further data have been gathered. Since the satellite in question (ATS-3) drifted off its station at 70° west longitude during October, 1976 and disappeared below the horizon at Legon shortly thereafter, the long, uninterrupted period of SI and TEC data has come to an end. Hence it seems best to now use all the data accumulated during the period (1-9-71 to 31-10-76) and produce final results relating to these parameters. This Chapter represents an attempt to present and summarise these results. They in no way negate, but rather reinforce the conclusions reached in the previous report.

It will be recalled that three parameters were under investigation: scintillation, as measured by the scintillation index (SI); total columnar electron content as deduced from Faraday rotation (TEC); and magnetic activity as reflected in the planetary K figure (KP). Each of the 62 months' data were used to determine hourly correlation coefficients between the parameters taken in pairs. These latter were referred to for convenience as SITEC, KPTEC, and SIKP. In general, these results can be analyzed to show the variation of the relationship between the two variables as a function of time of day, season, and sunspot cycle. These three aspects will be investigated for each pair of variables in turn.

SITEC

DIURNAL VARIATION:

This is depicted in Figure 3-1 (a). The curve is based on 42 months data; the months MJJA being omitted each year since the following figure shows that the relationship under investigation drops below the 1% significance level during those months. We summarize the results as follows:

- (1) There is a significant positive correlation between 4H and 8H
- (2) There is a significant negative correlation between 20H and 01H.
- (3) All these results are well above the 1% significance level.

SEASONAL VARIATION:

Figure 3-1 (b) shows the results. All 62 months' data went to make up this curve. The obvious conclusions are:

- (1) The morning positive correlation is relatively small during MJJA, while it is well above the 1% significance level for all other months.
- (2) The evening negative correlation shows an identical seasonal behaviour. Values fall below the 1% significance level in MJJA, but are well above it for all other months.

SUNSPOT CYCLE VARIATION:

Figure 3-2 shows the annual mean of the hourly correlation coefficients for each of five consecutive years. These extend from a time of relatively high sunspot number to sunspot minimum. We note that the relative shape of the plot is remarkably consistent from year to year.

Figure 3-3 investigates the behaviour of the morning and evening correlation coefficients through the five year period. Bars indicate one standard deviation on either side of the mean correlation coefficient. We must conclude that there is no statistically significant variation in either of these dependencies from one year to the next. Hence there is no significant sunspot cycle dependence in these relationships.

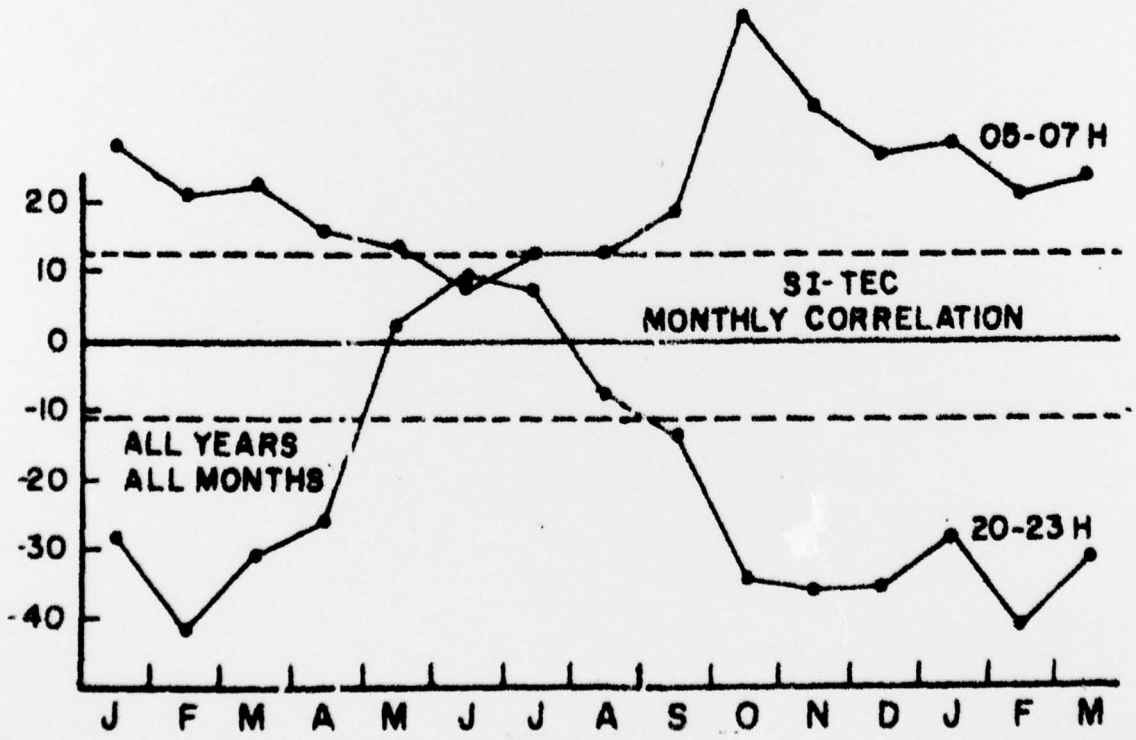
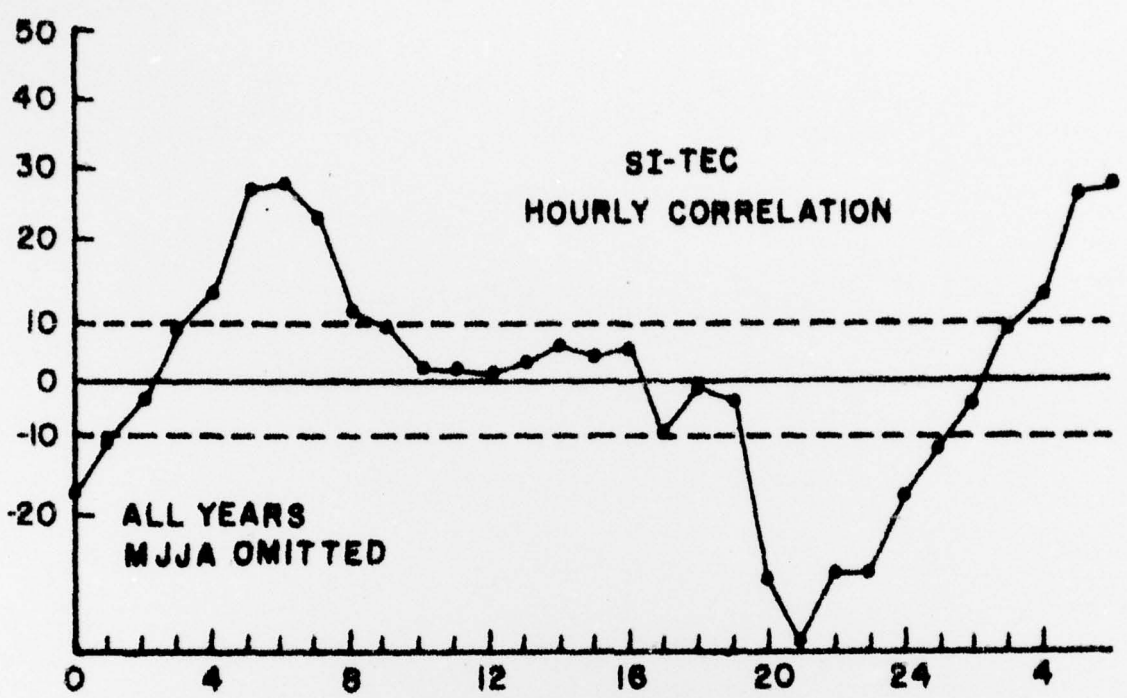
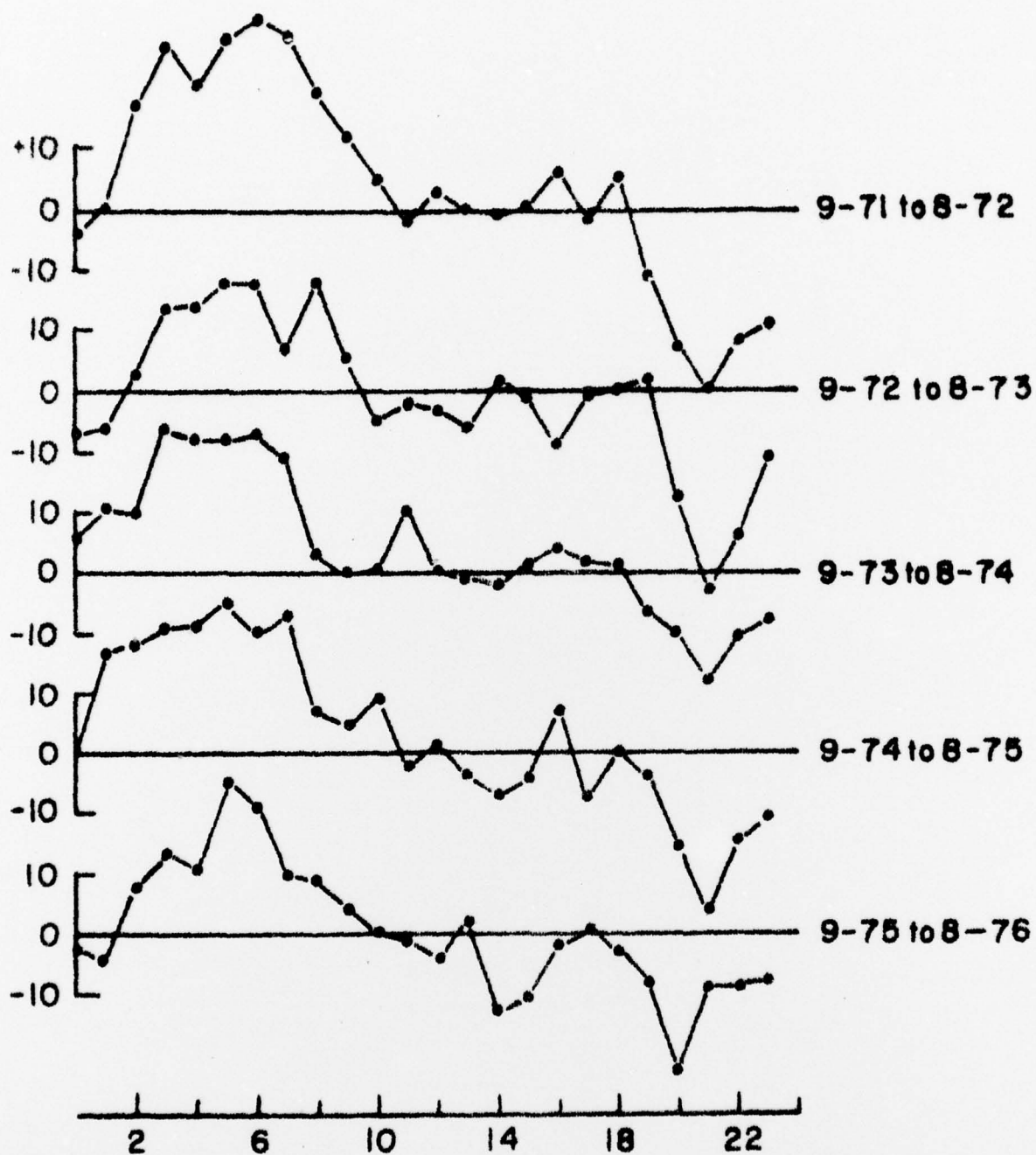


FIGURE 3-1



**HOURLY CORRELATION COEFFICIENTS BETWEEN SI AND
TEC FOR EACH OF FIVE YEARS**

FIGURE 3-2

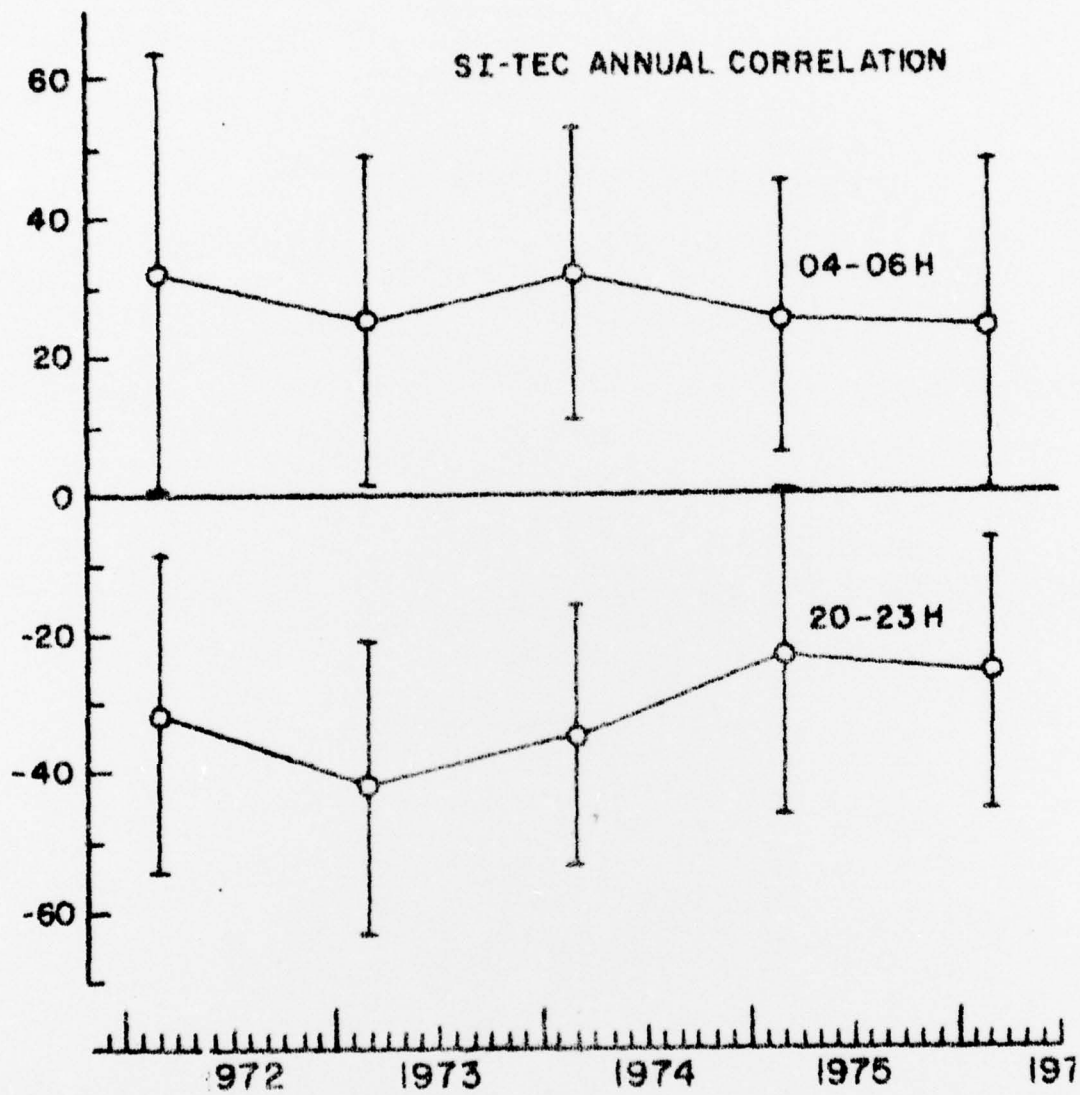


FIGURE 3-3

KPTEC

DIURNAL VARIATION

Figure 3-4(a) shows the diurnal variation of the dependence of TEC on the KP index. We note the following principal features:

- (1) There is a significant positive correlation between the two parameters at all hours of the day and night. This means that electron content is enhanced during times of magnetic disturbances, and this enhancement affects both daytime and nighttime values.
- (2) The effect is somewhat more pronounced during daylight hours.
- (3) The correlation is far above the 1% significance level at all times.
- (4) The results here are shown for the case where values of KP have a nine hour time lead on TEC are compared with KP values of nine hours ago. Since the previous report (Koster and Beer, 1975) showed that the correlation was highest with this time lead, the effect has not been further investigated here.
- (5) The correlation shows a fairly prominent peak centred on 20 hours local time.

SEASONAL VARIATION:

The correlation by months, (Figure 3-4(b)) shows the usual June solstice minimum. While the May value is the only one to fall below the 1% significance level, values for MJJAS are all well below the level for other months.

SUNSPOT CYCLE VARIATION:

Figure 3-4(c) shows the annual mean correlation coefficient for daylight hours for each of the five years investigated. The bars in the figure show one standard deviation above and below the mean of the 12 monthly values for each year. There does not appear to be any statistically significant difference in the correlation coefficient from one year to the next. We conclude that the connection between KP and TEC is operative during the entire sunspot cycle.

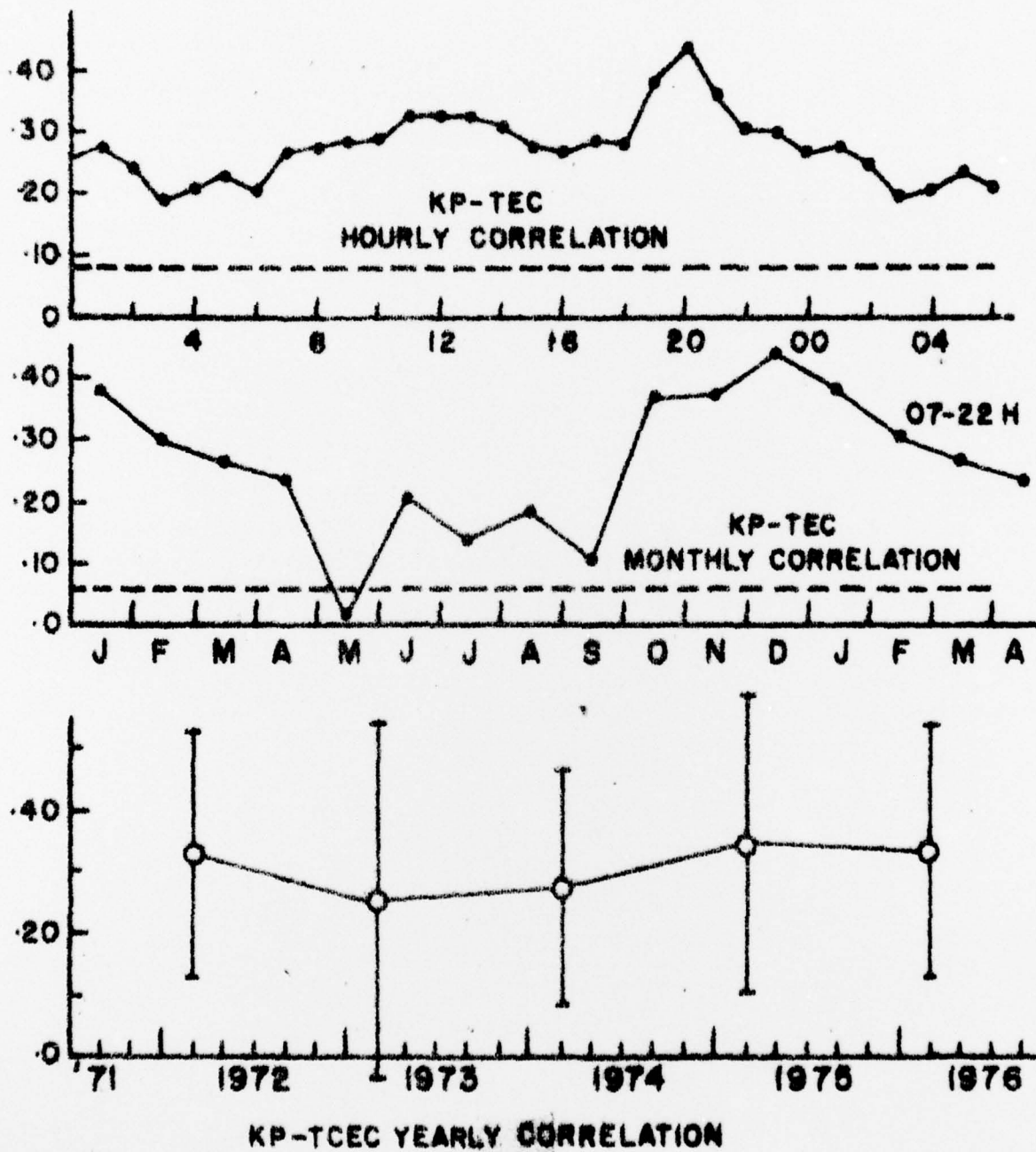
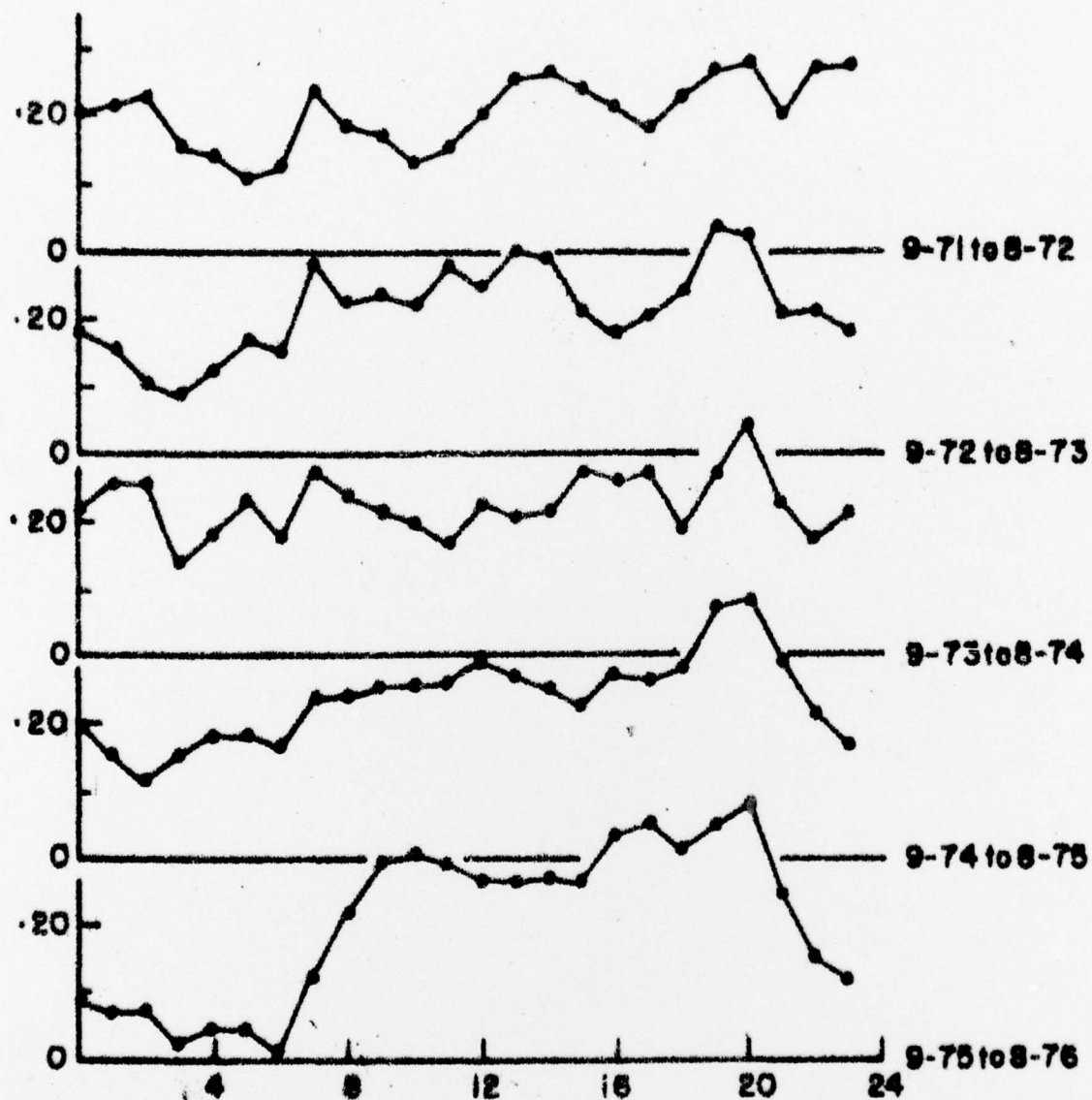


FIGURE 3-4



HOURLY CORRELATION COEFFICIENTS BETWEEN
KP AND TEC FOR EACH OF FIVE YEARS

FIGURE 3-5

Figure 3-5 shows the hourly correlation coefficient for each year taken separately. While all the curves show the positive correlation reported above, the relative enhancement of the effect during daylight hours is most apparent near sunspot minimum.

SIKP

DIURNAL VARIATION

Figure 3-6(a) shows the diurnal variation of the correlation between SI and KP. The graph includes data from the whole 62 month period, MJJA of each year being omitted, as was done in the case of SITEC, since the usual June minimum was known to hold in the relationship between these two parameters. This is confirmed in the following paragraph. In this case, we note the following points:

- (1) There is a significant positive correlation between the two parameters around sunrise. This is similar to SITEC, but the values are above the 1% significance level at 6H and 7H only.
- (2) The evening negative correlation is similar to that in the case of SITEC, and is above the 1% significance level from 20H to 03H inclusive.
- (3) The similarity of this curve to that for SITEC is remarkable.
- (4) It should be noted that the 9 hour time lead of KP has been introduced here too as was also done for KPTEC.

SEASONAL VARIATION

Figure 2-6(b) investigates the seasonal variation of the morning and evening correlation of SIKP separately.

- (1) The evening correlation (21H to 02H) is similar to SITEC in every respect. The effect disappears during MJJA.
- (2) The behaviour of the dawn correlation (6H to 7H) shows the expected minimum for JJA, the value for May being still well above the 1% significance level.
- (3) The significance of the dawn correlation also drops below the 1% significance level in DJ.

SUNSPOT CYCLE VARIATION

Figure 3-7 shows the annual mean of both dawn and evening correlations. As usual, the bars indicate one standard deviation above and below the mean value - determined from the 12 monthly values for the given year. As is true in the previous cases, the correlation between SI and KP seems to be largely independent of the sunspot cycle. Figure 3-8, which shows five consecutive years of hourly correlation coefficients, suggests that the morning maximum and the evening minimum in the value of the correlation coefficient is a consistent feature. Daytime values are of dubious significance, daytime scintillation being a relatively infrequent phenomenon.

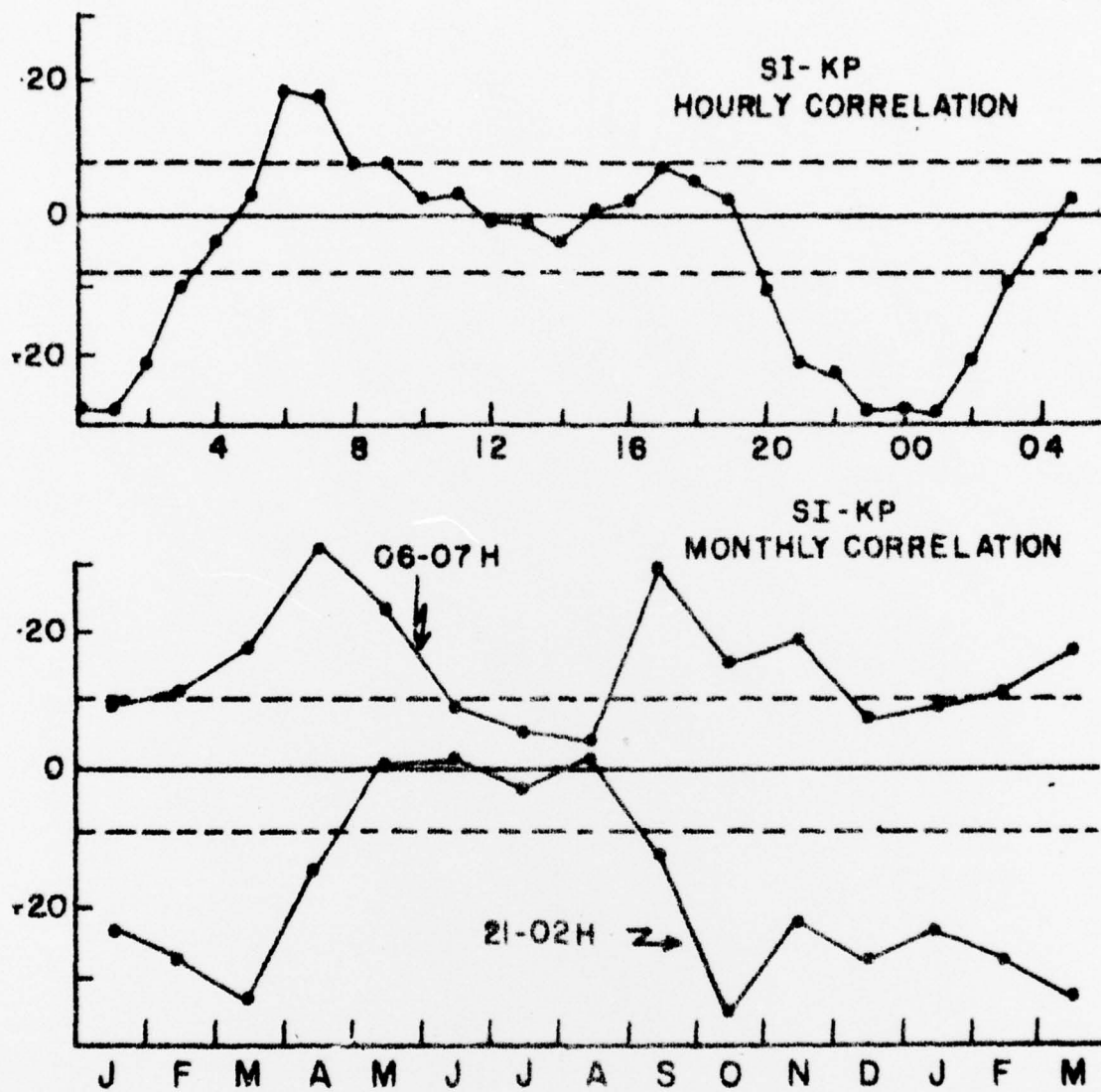


FIGURE 3-6

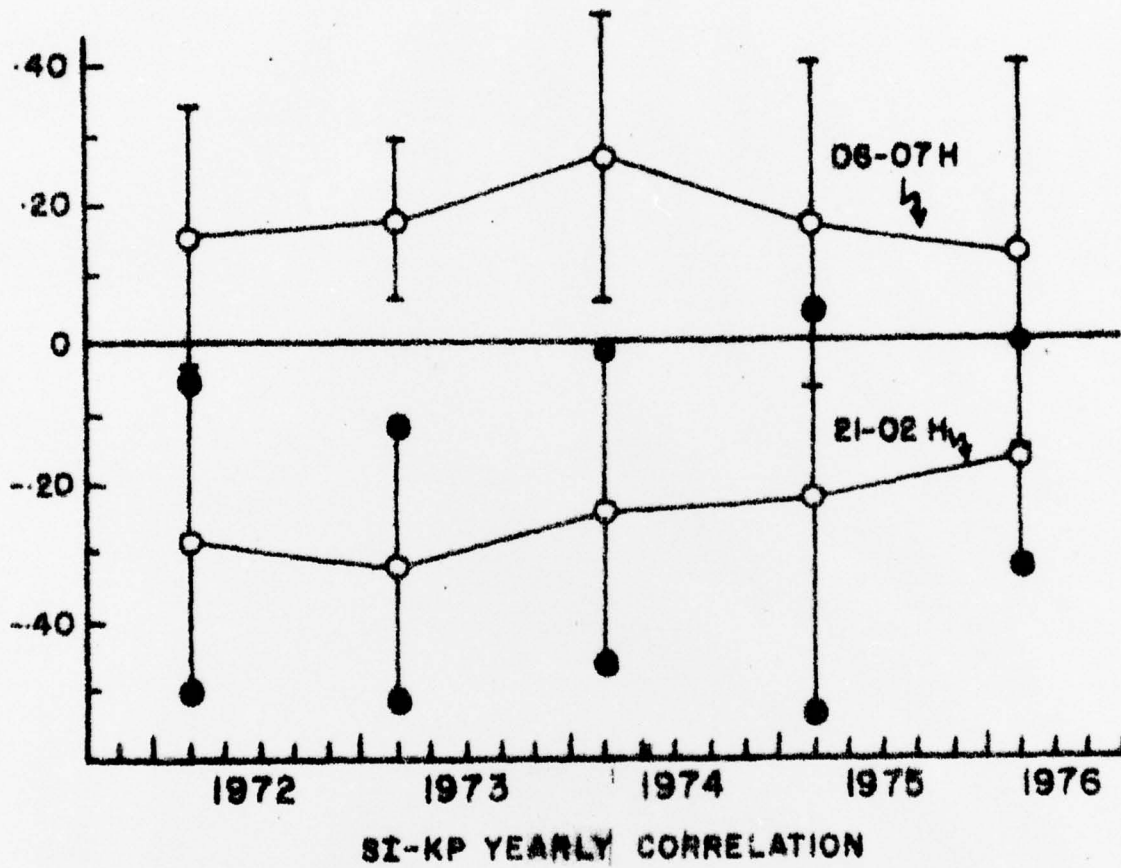
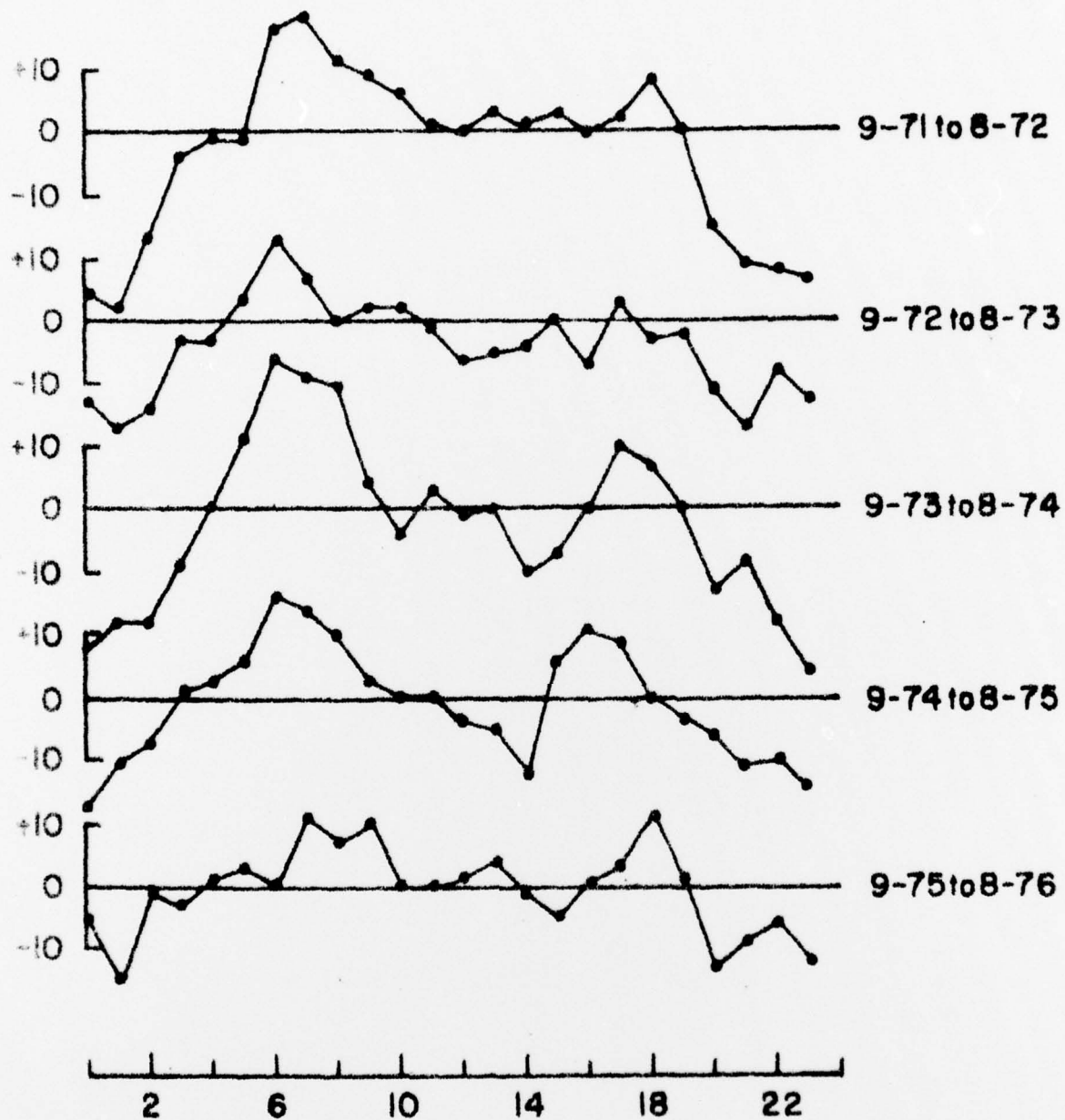


FIGURE 3-7



HOURLY CORRELATION COEFFICIENTS BETWEEN
SI AND KP FOR EACH OF FIVE YEARS.

FIGURE 3-8

CONCLUDING REMARKS

The dependence of scintillation on sunspot number and season, as given in Chapters 1 and 2 of this report, is part of a larger effort to separate out the dependence of scintillation on a large number of geophysical parameters. The dependence on elevation angle and observing frequency are currently under investigation.

The findings, in Chapter 3, concerning the inter-relationships between SI, TEC and KP complement and extend those previously reported (Koster and Beer, 1975), and give them an even more solid experimental basis. The speculation about their interpretation previously presented is still considered valid, and we do not add to it here. But these results present a number of relationships which any comprehensive model of the behaviour of equatorial ionosphere must be able to account for.

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- Koster, J.R. Ionospheric production rates and initial zenith angle at Legon. J. Atmos. Terr. Phys. 38, 611-614.
- Koster, J.R. and Beer, Tom. Interim Scientific Report No.2, 30 August, 1975.

